

# Coded Tissue Harmonic Ultrasound of Focal Hepatic Lesions: Comparison of Image Quality with Conventional Ultrasound

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**Background:** Harmonic waves are generated from nonlinear distortion of an acoustic signal under an ultrasound wave traveling through the body. These beams are integer multiples of a fundamental transmitted frequency. Potential benefits of harmonic imaging include improved contrast resolution and better lateral resolution. Decreased noise from side lobes improves the signal-to-noise ratio and reduces artifacts. A variety of implementations now exist to create tissue harmonic imaging (THI), including frequency filtering, pulse inversion/phase cancellation and coded harmonics. The purpose of this study was to evaluate the image quality of coded tissue harmonic ultrasound (US) compared to conventional US for focal hepatic lesions.

**Materials and Methods:** A total of 275 patients with focal hepatic lesions were scanned with both conventional and coded tissue harmonic US. The hepatic lesions were classified into cystic, hypoechoic, hyperechoic, and heterogeneous appearance according to sonographic features. Analysis of these lesions focused on comparing THI with conventional US for visibility and providing more diagnostic information. Image quality was assessed as excellent, good, satisfactory, poor or unsatisfactory.

**Results:** Images were considered better with THI in 174 cases (63%), particularly in cystic (76%) and hyperechoic (71%) lesions. Mean visibility scores of lesions with THI were 4.12 for cystic lesions, 3.75 for hypoechoic lesions, 4.07 for hyperechoic lesions and 3.64 for heterogeneous lesions.

**Conclusion:** THI significantly improved image quality in focal hepatic lesions, especially for cystic or hyperechoic lesions.

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KEY WORDS: • ultrasound • tissue harmonic imaging • focal hepatic lesion

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## INTRODUCTION

Sonographic tissue harmonic imaging (THI) is a new technique that produces diagnostic images by recording harmonic echoes produced by nonlinear propagation of ultrasound in tissue [1,2]. Tissue first compresses and then relaxes as each pulse of sound passes. This physical alteration produces peaks and troughs in the pulse wave pattern because the speed of sound is slightly higher in compressed than non-compressed tissue. These repetitive alterations in the sound pressure wave cause low-amplitude harmonic echoes that increase in intensity as the beam penetrates deeper. Multiple harmonics are produced, and their frequencies are higher integer multiples of the transmitted frequency [1–5]. In comparison, conventional ultrasound (US) waves are generated at the surface of the transducer, and the received signal is lower in intensity because the tissue attenuates it. Currently, the second harmonic (twice the transmitted frequency) is used for imaging [2].

Potential advantages of harmonic imaging include improved axial resolution due to shorter wavelength, better lateral resolution due to improved focusing with higher frequencies, fewer artifacts than with conventional US, lower side lobes and less likelihood of image degradation, and reduced defocusing effect of the body wall because harmonics are generated inside the body [6–10].

A variety of implementations now exist to create images exclusively from the second harmonic signal. These include frequency filtering, pulse inversion/phase cancellation and coded harmonics [7,10]. Previously published clinical studies have shown that frequency filtering and pulse inversion methods can significantly improve the visualization of both normal and pathologic tissues [6–12]. In this study, we used coded harmonics technology, which removes the fundamental from the received echo spectrum, based on the concept of encoding a digital signature as a sequence of transmitted pulse, and then eliminating the tagged echoes with signal processing on reception [10]. The LOGIQ 700 Expert system (GE Medical Systems, Milwaukee, WI, USA) is capable of generating US pulse sequences by taking a basic pulse unit and then repeating it and modulating its amplitude to form a train of pulses within one transmit firing (or over two or more firings per scan line). By choosing the appropriate coded sequence

of pulses for each transmit focal zone, wide-band harmonic imaging can apparently be realized even on high-frequency probes with frequency bands extending up to 12 MHz [10].

The liver is the biggest organ in the human body and is also involved in many diseases. US is the best screening modality for hepatic lesions. However, spontaneous respiratory movement makes hepatic lesions hard to detect, especially if they are beneath the diaphragm [11]. Therefore, we applied this new technique to detect lesions in the liver. The purpose of this study was to evaluate the image quality of coded tissue harmonic US compared to conventional US for focal hepatic lesions.

## MATERIALS AND METHODS

### Subjects

From August 2002 through July 2003 at our institution, 275 adult patients (136 men and 139 women; mean age, 59 years; age range, 33–79 years) underwent abdominal US examinations at which focal hepatic lesions were observed by one designated sonographer with more than 20 years of scanning experience.

### US studies

Imaging was performed using a single-vector format transducer (model 348C) and a commercially available US scanner (LOGIQ 700 Expert system, GE Medical Systems). The sonographer obtained similar views of abdominal lesions with both harmonic imaging and conventional US. Scanning parameters were optimized independently for each method, and all images were obtained using the same focal zone. The sonographer used an external video with cine playback mode to obtain identical images in two standard orthogonal planes. Images were obtained with the two methods in random sequence to facilitate masking for observers, and all images were stored on magneto-optical discs and CD-RW.

Harmonic images were acquired at a transmitting frequency of 2.0 MHz and a receiving harmonic bandwidth of 4.0 MHz. Conventional US images were obtained at a frequency of 3.5 MHz, which is commonly used for abdominal imaging in adults. Switching between harmonic and conventional US modes was achieved by means of a toggle switch on the scanner control panel.

### Lesion characteristics and analysis

Lesions were classified by radiologists into four groups based on their US characteristics: cystic, hypoechoic, hyperechoic and heterogeneous.

The technical parameters of the paired images were masked before independent classification by three radiologists into three categories: THI provided more information than conventional US; THI provided the same information as conventional US; and THI provided less information than conventional US.

### Image quality assessment and statistical analysis

Lesion visibility was graded on a five-point scale: 5 = excellent; 4 = good; 3 = satisfactory; 2 = unsatisfactory; and 1 = poor. Ratings for lesion characteristics and visibility were evaluated using descriptive statistics and the Wilcoxon signed-rank test.

## RESULTS

Harmonic imaging was better than conventional US for lesion visibility ( $p < 0.05$ , Wilcoxon signed rank test), especially in cystic and hyperechoic lesions. In cystic lesions, the mean lesion visibility score was higher with THI than with conventional US (4.118 vs 3.196; Table). Image quality with THI was superior to that with conventional US in 76% of cases (39/51) (Fig. 1). Similarly, in hyperechoic lesions, mean lesion visibility score was higher with THI than with conventional US (4.071 vs 3.257). Image quality with THI was superior to that with conven-

tional US in 71% of cases (50/70). THI depicted tumors with a hypoechoic rim (Fig. 2) and cystic lesions with a septum or small cysts (Fig. 3) more clearly than conventional US. It also increased lateral shadow resolution (Fig. 4), helped in distinguishing lesions adjacent to the diaphragm (Fig. 5), and hyperechoic lesions in fatty liver (Fig. 6).

The difference in lesion visibility between THI and conventional US images was less marked for hypoechoic and heterogeneous lesions (Fig. 7), superficial (Fig. 8) or deep lesions (Fig. 9), and patients with obesity or fatty liver (Fig. 10). In hypoechoic lesions, the mean lesion visibility score with THI was 3.747 and that with conventional US was 3.176 (Table); the image quality with THI was superior to that with conventional US in 57% of cases (52/91) (Fig. 1). In heterogeneous lesions, the mean lesion visibility score with THI was 3.635 and that with conventional US was 3.175 (Table); the image quality with THI was superior to that with conventional US in 52% of cases (33/63).

However, THI was inferior to conventional US in patients with hepatocellular carcinoma post-transcatheter arterial embolization (TAE) (Fig. 11) and gave an indistinct margin in some heterogeneous lesions. There were no statistically significant associations between lesion visibility and age or gender.

## DISCUSSION

US is often the initial examination requested in patients with suspected liver pathology, yet reverberation artifacts from the body wall and a small

**Table.** Image quality in tissue harmonic imaging (THI) and conventional ultrasound (cUS)

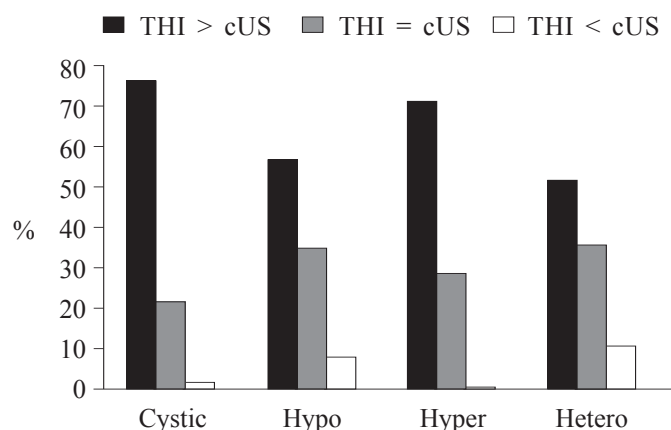
Lesion visibility	Cystic		Hypo		Hyper		Hetero	
	THI	cUS	THI	cUS	THI	cUS	THI	cUS
5 (excellent)	20	1	26	1	25	1	17	1
4 (good)	19	19	26	34	25	27	16	23
3 (satisfactory)	10	21	32	38	20	33	23	26
2 (unsatisfactory)	2	9	4	16	0	7	4	12
1 (poor)	0	1	3	2	0	2	3	1
Total	51		91		70		63	
Mean	4.118	3.196	3.747	3.176	4.071	3.257	3.635	3.175
Standard deviation	0.855	0.817	1.023	0.806	0.799	0.769	1.088	0.807

Cystic = cystic lesion, Hypo = hypoechoic lesion; Hyper = hyperechoic lesion; Hetero = heterogeneous lesion.

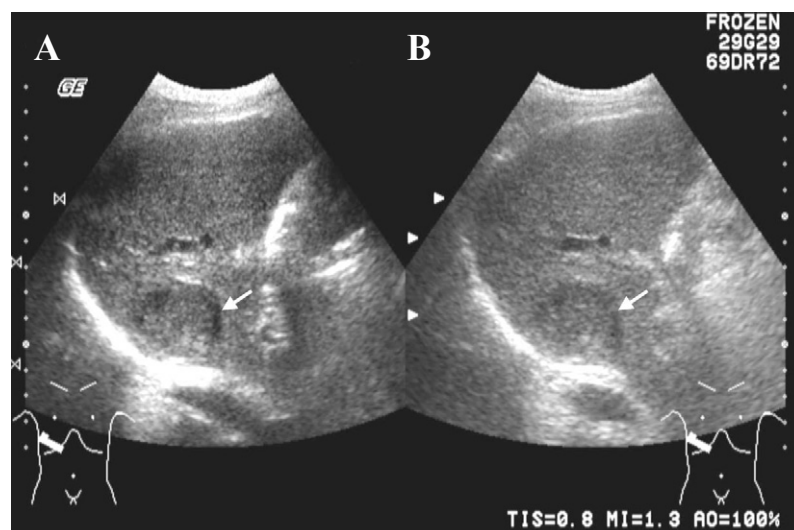
acoustic window during intercostal scanning can limit visualization of anatomic structures such as small portal veins and bile duct branches. Image clutter in the right upper quadrant can impair visualization of low-contrast focal lesions, which may be similar in echo texture to the background liver [10]. In our study, THI gave better lesion visibility than conventional US in 64% of cases; therefore, detection of subtle lesions was improved. THI has a somewhat different appearance to that generated by conventional fundamental pulse-echo US, so radiographers need to learn new diagnostic standards for the normal appearance of solid structures [7]. The use of higher effective frequencies for imaging yields an improvement in axial resolution and thereby improves visualization of smaller objects along the axis of the beam. Higher frequency US waves produce narrower beams as a result of

better focusing of the waves, which improves lateral resolution. An improvement in lateral resolution provides better visualization of smaller lesions that exist side by side within the field of view [10].

Harmonic imaging improves signal-to-noise ratios by reducing noise from side-lobe artifacts in the near field and echo detection from multiple scattering events [6]. This reduced noise was most likely responsible for the superiority of harmonic imaging over conventional US in the visualization of cystic lesions. Harmonic imaging helped differentiate cysts from hypoechoic solid masses. There was better clarity of the content of cysts, which helped differentiate artifacts from true echogenic structures within cysts, such as debris, hemorrhage and septation. THI was superior to conventional US in the visualization of heterogeneous lesions due to better tissue-to-lesion contrast, especially in detect-

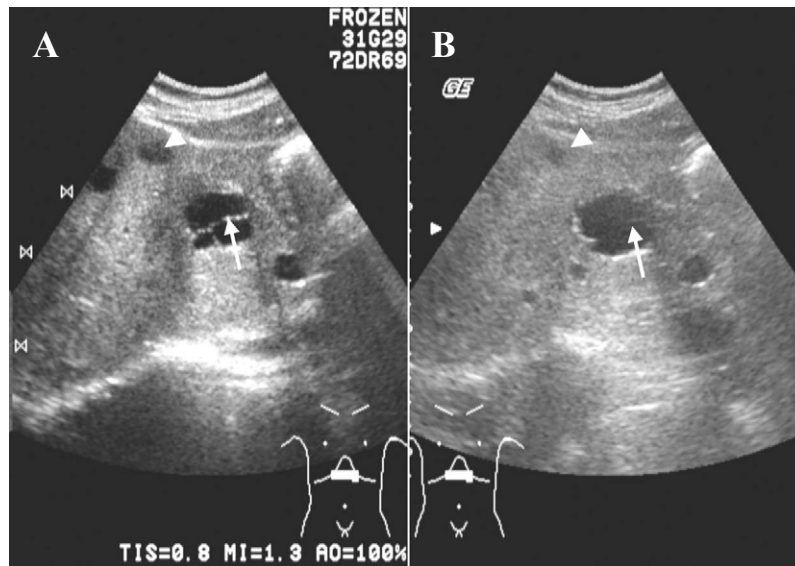


**Fig. 1.** Comparison of the image quality of focal hepatic lesions between coded tissue harmonic imaging (THI) and conventional ultrasound (cUS). Cystic = cystic lesion; Hypo = hypoechoic lesion; Hyper = hyperechoic lesion; Hetero = heterogeneous lesion; THI > cUS = THI better than conventional US; THI = cUS = THI the same as conventional US; THI < cUS = THI inferior to conventional US.



**Fig. 2.** Tumor with hypoechoic rim: hepatocellular carcinoma adjacent to the diaphragm. Tissue harmonic imaging (A) delineates this hepatic tumor (arrows) better than conventional ultrasound (B).

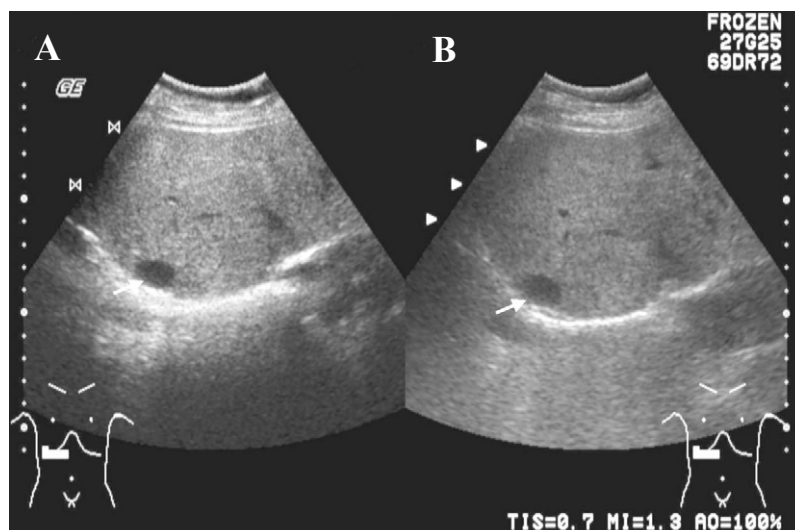




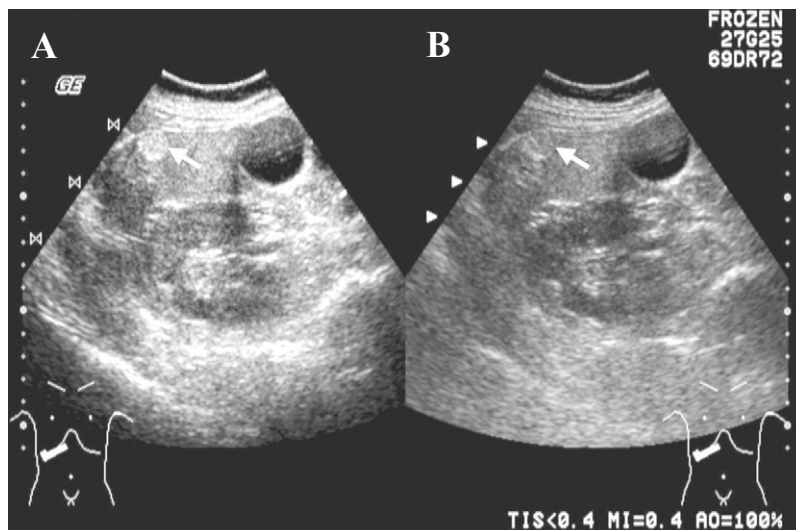
**Fig. 3.** Cystic lesion with septum: multiple hepatic cysts in the left lobe of the liver. Due to increased tissue contrast, tissue harmonic imaging (THI) (A) demonstrates septation within the biggest cyst better than conventional ultrasound (B) (arrows). Other superficial smaller cysts are also more obvious on THI (arrowheads).



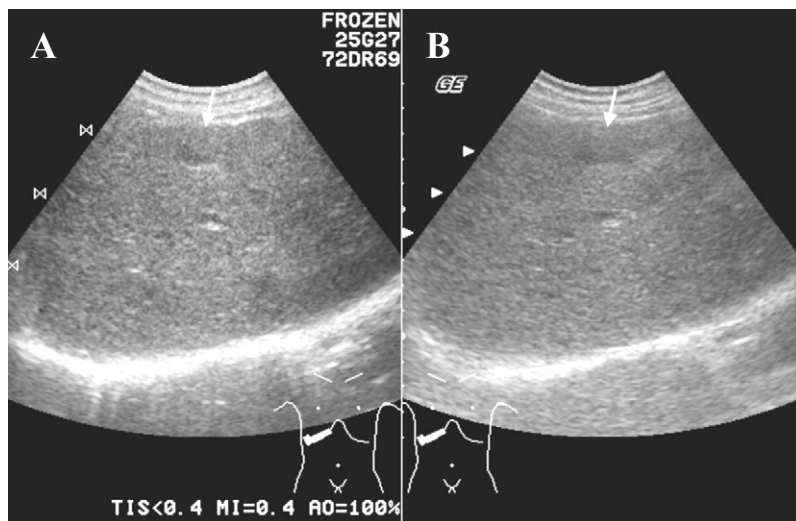
**Fig. 4.** Tissue harmonic imaging (A) demonstrates better image quality for lateral shadow resolution than conventional ultrasound (B) (arrows).



**Fig. 5.** Hepatic cyst adjacent to the diaphragm in the right lobe of the liver. The internal anechoic nature and posterior enhancement are clearer on tissue harmonic imaging (A) than on conventional ultrasound (B) (arrows).



**Fig. 6.** Hyperechoic lesion in fatty liver: small hemangioma located at the superficial position of the right hepatic lobe and surrounded by fatty infiltration in the liver parenchyma. The lesion is more clear-cut on tissue harmonic imaging (A) than on conventional ultrasound (B) (arrows).



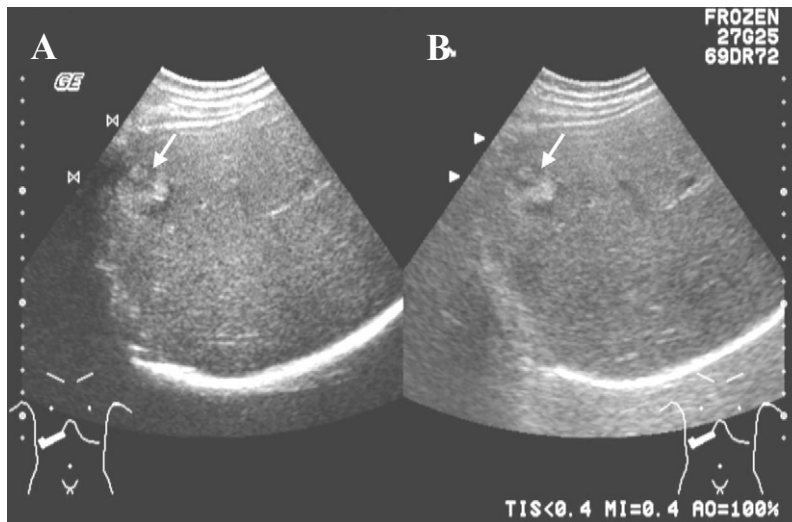
**Fig. 7.** Hypoechoic nodule located at the superficial position of the right hepatic lobe. The margin is shown more distinctly on tissue harmonic imaging (A) than on conventional ultrasound (B) (arrows).

ing capsule, internal cystic or hyperechoic content. However, there were no differences between THI and conventional US in the detection of diffuse heterogeneous lesions.

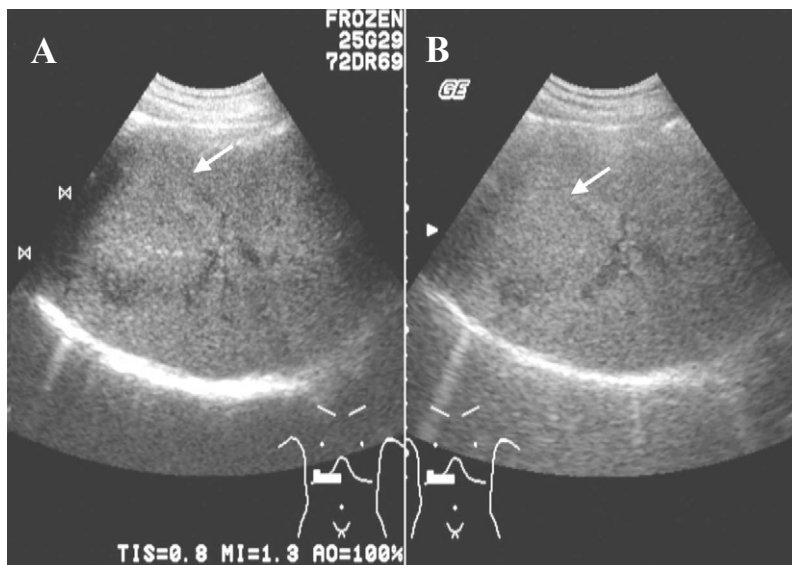
For patients with diffuse fatty infiltration in the liver, penetration of the US beam was better in conventional US. As the harmonic imaging effect is most pronounced in the midfield, the generation of harmonic waves without contrast agents will only be apparent in the middle of the US image. So, when the lesion was in the far mid or far fields from the body wall, THI was inferior to conventional US in lesion visualization. Conventional US showed better image quality than THI in the visualization of the internal texture of mass lesions with ring calcification. Although THI demonstrated better definition

of posterior acoustic shadows in calcification, the receiving energy of the harmonic waves was far less than that of the fundamental waves, causing inferior image quality in the internal texture compared to conventional US. The same situation was noted in patients with hepatoma post-TAE. There was better definition of the remaining lipiodol and signal-to-noise ratio in the hepatoma with THI, but there was no improvement in detection of the tumor margin, which was even worse than with conventional US.

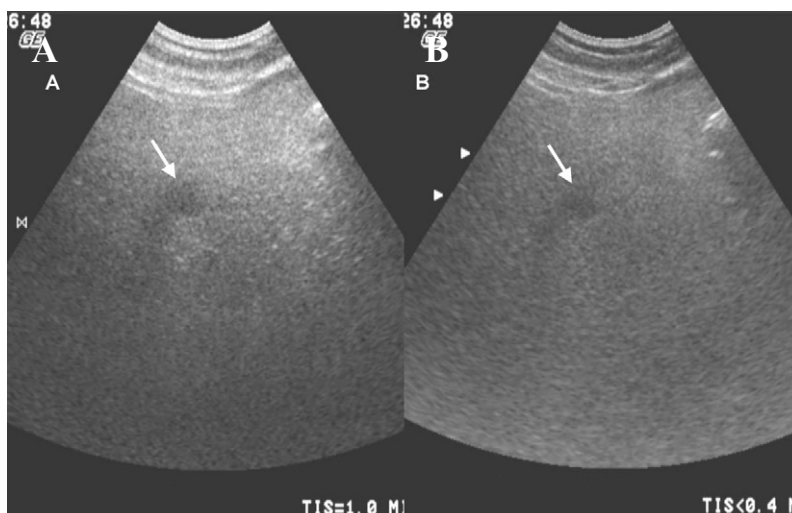
Although the difference in image quality between THI and conventional US may not be as marked as imagined, THI does help in increasing confidence of diagnosis. By the small improvement in image quality, we can be more assured of lesion detection and differential diagnosis. THI is useful for commer-



**Fig. 8.** A superficial hepatic lesion: heterogeneous nodular lesion located at the superficial portion of the right hepatic lobe. There is no difference in lesion visibility on tissue harmonic imaging (A) and conventional ultrasound (B) (arrows).

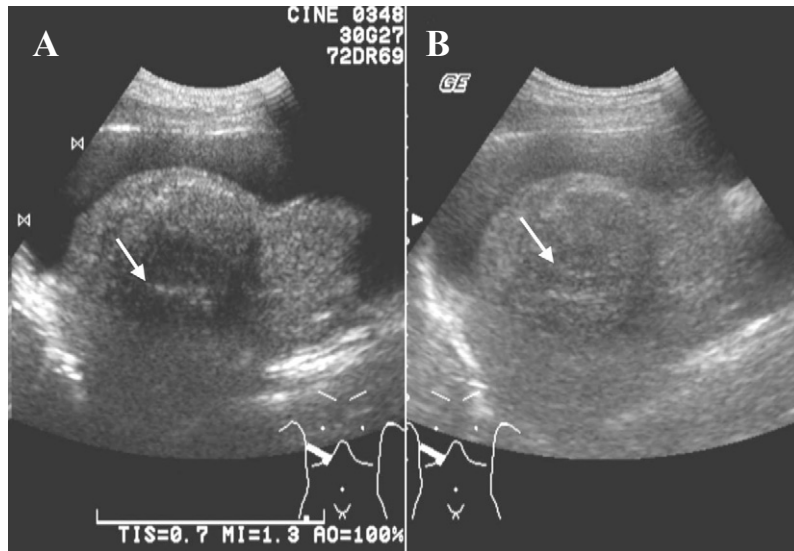


**Fig. 9.** Deep hepatic lesion: hypoechoic mass lesion located in the deep portion of the right hepatic lobe. There is no difference in lesion visibility on tissue harmonic imaging (A) and conventional ultrasound (B) (arrows).



**Fig. 10.** Hypoechoic lesion in severe fatty liver. Lesion visibility is decreased on both tissue harmonic imaging (A) and conventional ultrasound (B) (arrows).





**Fig. 11.** Hepatocellular carcinoma (HCC) post-transcatheter arterial embolization. Although the internal hyperechoic areas in the embolized HCC are more distinct on tissue harmonic imaging (A), the remaining solid tumor texture was clearer on conventional ultrasound (B) (arrows).

cial and daily use, with only a little more expense incurred than with conventional US.

## CONCLUSION

We found that coded THI significantly improved image quality for focal hepatic lesions, especially in cystic or hyperechoic lesions. We suggest that harmonic imaging could be used as the initial and essential method for hepatic US examinations, especially with blurry or indeterminate lesions on conventional sonographic imaging.

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